THE MATHEMATICIAN, THE FARMER AND THE WEATHER

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IT may have been true when Mark Twain said it, "Everybody talks about the weather, but nobody does anything," but now-a-days the mathematicians are doing something. They are hitching the weather to the engine of a formula, measuring it with the yardstick of an equation, and weighing it in the balances of a co-efficient. They can tell how many million dollars a half inch of rain on the fifth of August will add to the corn crop of Ohio; how many additional automobiles the farmers can purchase as a result of a week of warm weather while the wheat heads are filling; and how much smaller the world's supply of cotton will be because of an August drought in Georgia.

Aspiring poets used to lament that all the possible figures of speech were long since exhausted, but the poets of to-day still find something new to say and new ways to say it. So the prosaic, practical scientists are saying something very new about three of the oldest subjects of human thought, weather, farming and mathematics. The weather is the oldest of them all as a basis of observation and remark; the practise of agriculture began early in the history of civilization, and the development of mathematics began soon after, notably among the Egyptians, and was carried to a high degree of excellence in some lines by the Greeks. Yet each of these is the subject of an extremely new and modern science. Meteorology, the science of the weather, is one of the newest of the sciences, and is yet in its infancy. Its beginnings date back to some observations made by Benjamin Franklin, but its application began a century later, just after the Civil War. Something of the growth of the modern science of agriculture, principally due to the work of the agricultural experiment stations, is known to all. In the old science of mathematics new theorems, processes and devices are constantly being developed. But now appears a group of men with an original idea. Knowing something of the modern aspects of each of these sciences, they are combining them and using the refined and elegant processes of mathematical statistics to determine the effect of various kinds of weather upon the

crops in their different stages of development, to ascertain the farmer's risk from unfavorable weather, and to find definite relations between weather happenings in different parts of the globe.

The mathematical processes are due largely to Professor Karl Pearson, of England, who has applied them primarily in the fields of biology and anthropology. In this country, the leader in the application of these methods to the problem of determining the influence of the weather on the crops is Professor J. Warren Smith, of the United States Weather Bureau, whose work in this line began in Ohio several years ago. For example, he has shown that the yield of corn in Ohio is very largely dependent upon the amount of rain in June, July and August. When the July rainfall is less than three inches, the average yield is 30 bushels per acre, when it is five inches or more, the yield is 38 bushels; which means that these two inches of rain have added 27,300,000 bushels to the corn crop of this State, worth at 1919 prices about $35,000,000. When the July rainfall is three and a quarter inches, the yield is 15,000,000 bushels greater than when it falls short of this amount by half an inch. Each quarter of an inch increase between the totals of two and four inches means an added value of about $7,800,000. Taking the four great corn-growing states of Indiana, Illinois, Iowa and Missouri, the addition of half an inch to a total of two and three quarters inches adds ten bushels per acre to the yield on the average. This thin layer of water is worth at present prices about $13 an acre, or a total for these four states of the Corn Belt of the significant sum of $4,000,000,000. Truly, if corn is king in this region, water is the power behind the throne.

But not content with this victory, the agricultural meteorologist advances to the next line of defense with the relentless weapons of statistical analysis, the machine guns of mathematics, and finds that the most important twenty-day period in Ohio is from July 21 to August 10; and finally goes over the top and locates the critical period in the first ten days of August. This is the time when the half inch or the quarter inch of rain is of the most value, and when you must have it if you are to get a big crop of corn. And this is the period immediately following the blossoming of the corn. Now, this idea of "critical periods" is new, the idea being that there are certain short periods of time in the growth of any crop during which its future prospects are largely determined, "a tide which, taken at the flood, leads on to fortune." In short, favorable weather at these times will produce a good crop and unfavorable weather

a poor one. In some crops this is a single short period; in some temperature is the most important, in others it is rainfall or sunshine.

Food is brought to the plant by the moisture in the soil and is converted into vegetable tissue by heat and by the direct action of the sun's rays. For every species of plant there are certain best temperature and moisture values, varying at different periods of growth. If these best values occur at the critical periods, excellent crops are certain, barring accidents. And here we arrive at a practical application; the climate of most places in the United States is pretty well known and completely exhibited in published tables. When tables of the critical periods of plant growth, together with the meteorological factors, whether temperature, rainfall or sunshine, most affecting growth at these times, likewise become available, we shall have but to compare the two sets of tables to determine whether a specific crop is climatically well adapted to a particular district. Further, there are ways of advancing or retarding, within certain limits, the time of occurrence of the critical periods, thus bringing them into the time when favorable weather is more likely to occur. This may be done by the use of an earlier or later variety, by varying the time of seeding, by cultivation, or by the use of fertilizers. Moreover, by cultivation, a quarter or even a half inch of moisture may be conserved, if the farmer knows just when it is most important to conserve it. If these methods fail, and the weather is still frequently unfavorable at critical periods, it will be necessary to substitute some other crop. In some cases these important periods are far enough ahead of harvest to enable increased attention to be given to other crops in the same year. For instance, the rainfall of May is the most important factor in the hay crop in most of the northern United States. If at the end of May the rainfall has been light, other forage crops may be planted to take the place of hay. The application of all this to farming under irrigation is obvious. In our arid and semi-arid west, the sun may be depended upon to supply an abundance of energy, and if just the right amount of water is applied at the right time, remarkable crops result. Hence the importance of knowing the right time.

I have referred principally to Professor Smith's study of the effect of the weather on the yield of corn in Ohio, but many other interesting results have been obtained, both by him and others, and both in this country and in Europe. Take wheat for example, one of the oldest and probably the most important of cultivated crops. In the growing of winter wheat, which is

exposed to all sorts of weather for nine months, through fall, winter, spring and summer, the weather of three or four ten-day periods in May and June is found to influence the crop to a much greater extent than that of all the rest of the time combined. These are the critical periods in the development of winter wheat, and they are associated with certain definite stages in the growth of the wheat plant. When the wheat is "jointing," that is, growing rapidly in height, cool weather is demanded, but later, while the heads are filling, it must be warm, and in between these periods, during the ten-days when the "boot" from which the head emerges is forming, dry weather is necessary for the best growth. There is indication also that cool weather is advantageous while the wheat is blossoming, and warm while it is ripening. In addition, a weight of evidence is accumulating that a heavy March snowfall is decidedly detrimental, contrary to the prevailing popular opinion.

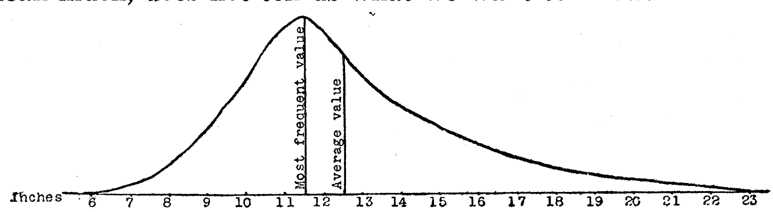
In the great spring wheat centers of North and South Dakota, it has been shown that the yield depends largely on the rainfall of May and June and the temperature of June, but no shorter critical periods have as yet been established. To obtain a large crop, the rainfall of May and June should be above the average and June should be cooler than the average. In North Dakota, which is the drier and cooler of the two states, a good rainfall is more important than cool weather, but in South Dakota temperature is in a great measure the determining factor, while in the neighboring State of Minnesota, variations in either temperature or precipitation during these months have little effect on the yield. No general rules for the entire country can be made, but each section must be studied with reference to its normal climate.

Consider, as another example, that staple of our dinner tables, the potato. A cool and wet July makes the potato crop in the Mississippi Valley. Cool weather is desirable all summer and wet weather during June, July and August, but July is the most important month and the first ten days of July the most important short period. This is the ten days following blossoming. If it is cool during this time with a good supply of moisture, and in addition the moisture supply has been fairly good during the previous two or three weeks, the prospects for a large crop of potatoes are excellent. If these conditions have not obtained, the yield will be small. If the water supply can be controlled by irrigation, it is of the greatest importance that it be sufficient at this period.

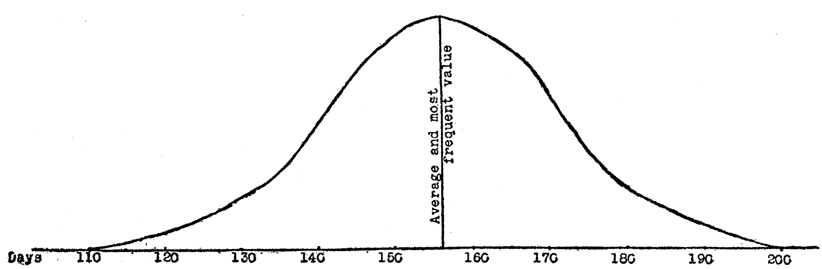
In the great Cotton Exchange in New York and in the primary cotton markets of the South the price of cotton has always fluctuated from day to day during the growing season with the daily reports of weather conditions in the Cotton Belt, where the world's supply of this staple is largely produced. But it has fluctuated erratically and without any solid knowledge of the exact amount of influence the weather may have upon the yield. Recently, however, a well-known American economist and statistician has shown that he can predict the total yield with remarkable accuracy by mathematical analysis from a knowledge of the average weather conditions from May to August, an accuracy greater than that of the estimates based on the condition figures of the Government crop reports. The favorable weather conditions differ somewhat in the different sections of the Cotton Belt, extending from Texas to South Carolina, but the most important requirements are that May shall be dry, June both warm and dry, and August cool and wet, a cool and wet August being of most importance. Sitting in his New York office, without even having seen a cotton plant growing and without receiving any reports as to the progress of the crop, the master of the newer statistics can at the end of August insert these weather values in his formula and tell how much cotton will be ginned in the South during the following autumn and winter. Such, in the hands of experts, is the magic in those bugbears of our school days, arithmetic and algebra!

There is another phase of weather, not directly connected with crop yields, towards which the powerful weapons of the mathematician have been directed. This may be called the application of frequency curves to climatic phenomena. A frequency curve offers a systematic method of examining the variations in a series of events, and, as applied to weather and climate, may be used to determine how often the summers will be too hot or too dry for a particular crop, or the winters too cold, or the growing season too short. The simple average, as usually given in climatic tables, is not sufficient. We must know how the individual years arrange themselves around the average. For, though these climatic events occur according to the laws of chance, they do not all follow the simple law by which, if you flip a coin a large number of times, heads and tails will appear with equal frequency. On the contrary, some of these happenings form "skew" curves; the rainfall, for example. In parts of the semiarid west an annual precipitation of twelve inches is considered sufficient for the growing of dry land grains, but that average will probably be made up of a few

years with much more than twelve inches and many years with amounts somewhat less than twelve. Though twelve is the average, it is not the most probable amount, and falls of less than twelve are more likely to occur than those of more than twelve. In such cases the distribution of events about the average is unsymmetrical, askew, and the average does not mean much, does not tell us what we want to know.



SKEW FREQUENCY CURVE SHOWING DISTRIBUTION OF ANNUAL PRECIPITATION AT CORINNE, UTAH. Average value, 12.5 inches; most frequent value, 11.5 inches.



SYMMETRICAL FREQUENCY CURVE SHOWING VARIATION IN LENGTH OF GROWING SEASON AT DENVER, COLORADO. Average and most frequent values coincide in 156 days.

The farmer or buyer wants to know not only what the average amount is, but how often in the course of ten or fifty years the amount will fall so far short of the average as to be entirely inadequate. This the makers of the frequency curve can tell him much more accurately than he could do for himself by simply counting the number of times it has been insufficient in the past ten or fifty years. In the northern portion of the orange-growing section of Florida, once in a good many years the trees are killed or badly frozen back by a winter cold wave. To know how often this is liable to occur is of prime importance in fixing the value of the land for orange-growing purposes. Similarly, in peach-growing sections, farther north, peach trees or the buds for next year's crop are subject to winter killing, and in nearly all fruit-growing sections the crops are liable to injury by late spring frosts. In early vegetable farming, the farmer frequently wants to take the risk of having his crops killed once in five or ten years in order to be in the market early in the other years. Is it better for him to go it

blindly, depending on his own impression of the proper date of planting, or to rely on the theoretical determination of the risk, which in 73 per cent. of the cases will lead to no unexpected losses, and in 94 per cent. to not more than one such loss in a period of twenty to thirty years?

In such cases as these the object is to determine the average interval between the occurrence of certain unfavorable conditions, such as insufficient rain, late spring frosts, early autumn frosts and other adverse events. This is the question that is answered by these curves, for by a little additional calculation the "frequency" curve becomes an "average interval" curve. By the use of these devices of the mathematician, it becomes possible from the examination of a limited number of observations to obtain a reasonable estimate of events as they will occur in an unlimited series of observations and hence to predict what is going to happen on the average in the next 20 or 100 or 1,000 years. Of course, it is not possible to tell by these means, nor by any others now known, just when such unfavorable events will happen. They may occur in two successive years and not again for 20 years. But, though they appear to happen fortuitously, in the long run they will occur the number of times indicated by the curve, and it is the performance of the land and the weather in the long run that determines values, though to the individual farmer the events of a few specific years may be of first importance.

The application of the statistical method to this individual phase of the problem, in what has been called "weather insurance," offers a legitimate opportunity for an extension of the field covered by insurance companies. We now have marine insurance, which includes perils of the sea due to storms, also hail and tornado insurance in certain parts of the country, but the idea may be greatly extended. Basing the work upon the methods I have described and upon the accurate climatological data collected by the Weather Bureau, there should be a statistical determination of the farmers' many risks from unfavorable weather conditions. Then the proper charge against the weather hazard can be made, and unseasonable and unusual weather will cease to be a calamity to the individual, just as the financial losses by fire and death are minimized in fire and life insurance, and the burden which is at present carried by individual losses and by depreciation of land values will be more widely distributed.

With such insurance well established it will be applicable in a wider field than the distribution of the individual risk. The

insurance rate quoted on a farm will give the purchaser valuable information. The country banker and storekeeper, who frequently carry the farmer through bad years, will be able to insure themselves against a great drain upon their resources in any one year. Instead of the haphazard, unbusinesslike method of taking unknown chances, which characterizes much of the present practice, the weather becomes a determinate risk in farming, a risk that can be stated more easily and more accurately than most other business risks.

Turning now from the numerous climatic problems of the agriculturist to those even more extensive fields of investigation, the physics of the atmosphere as a whole and the interrelations of its various parts, we find that the mathematical weather men have brought to light another series of interesting and curious facts. When an English scientist announces that it will be warm in Cairo, Egypt, to-morrow, since it was cold in London to-day, and that the rainfall will be unusually heavy in England this winter, since it was unusually light in Cuba last summer; when another says that a light rainfall in Chile during the period from May to August will be followed during July to October by more than ordinary floods on the Nile; when a Japanese mathematician says that the rice crop in northern Japan will be large this fall, since the barometer was unusually high last spring over China; when the scientists begin making such long range and curiously disconnected forecasts as these, it would seem that they are beginning to understand something of how this complicated atmosphere of ours works. As a matter of fact, they are conservative, and do not make any such forecasts for individual periods, but they have shown that on the average and to a great extent such relations do hold.

Many such correspondences between weather happenings in widely separated parts of the world have been shown. The rainfall of the central United States shows a direct correspondence to that of central South America, and both show an inverse relation to the rainfall of Australia. A forecast of the temperature at Berlin in March and April is possible at the end of December from the temperature at Christiania, Norway. When the April temperature at Irkutsk, Siberia, is higher than the normal, we may expect with a high degree of probability that the temperature at San Francisco in the following July will be abnormally low, and conversely. The higher the barometric pressure in the Argentine and Chile during March and April the greater will be the monsoon rainfall of India the following July and August. Florida and southern California refuse to pull

together in the matter of weather. Especially in the winter months, when one is warmer than normal, the other insists upon being cooler. Starting with San Diego as a basis of comparison and moving east and north, we find that the temperatures show a decreasing correspondence to those at San Diego, until, in the Mississippi Valley, the relation changes from positive to negative, and the eastern part of the country generally has temperature conditions opposite to those in southern California, culminating at Jacksonville, Florida, in a high degree of contrariness. Thus, it is fortunate for the orange market that freezes are not likely to occur in Florida and California in the same winter.

Such are some of the curious but apparently unimportant facts which have been revealed by the application of these novel methods of investigation to the study of climatic data. They are evidence that our entire atmosphere functions more or less as a unit, and though some of the results may seem at first sight to be of little moment, they promise in the end to prove of the greatest value. Their significance lies in the fact that they are leading toward an understanding of those great motions and shiftings of the atmosphere which cause our changeful weather, and make one winter to differ from another winter in severity as one summer differeth from another summer in torridity. A thorough understanding of these movements should, in time, lead to the solution of that fascinating problem of the climatic forecast, now the realm of charlatans, but the dream of real scientists, which aims at predicting the general character of a season months in advance. When that time comes, the mysteries of the weather largely will have vanished, and the meteorologist may say with the Wise Man in Yeats's play, "I have made formations of battle with Arithmetic that have put the hosts of heaven to the rout."